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CARBOHYDRATE-ELECTROLYTE SOLUTIONS DURING FIELD TRAINING: ACCEPTABILITY AND EFFECT ON ELECTROLYTE HOMEOSTASIS

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The views of the authors do not purport to reflect the positions of the Department of the Army or the Department of Defense. Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 in Use of Volunteers in Research.

ABSTRACT

Two 2.5% carbohydrate-electrolyte solutions (CE1 and CE2) were compared to plain water (W) and a flavored water placebo (FW) to evaluate their acceptability and consumption during field training in hot weather. Hedonic ratings and consumption of CE2, FW, and W were similar and significantly higher than CE1. FW and W groups consumed the largest amounts of test beverages. For all subjects, average sodium and potassium intakes were 4.2 ± 0.1 g and 3.4 ± 0.07 g, respectively, and serum levels were not physiologically different after 8 days. If food intake is adequate, consumption of water or FW is adequate to maintain electrolyte homeostasis.

INTRODUCTION

When unacclimated individuals must perform heavy work in a hot environment, extensive dehydration and heat casualties may incapacitate a military unit. Loss of more than 2% body weight from sweat can affect both performance and recovery from physical activity (1,2,3). Significant loss of water with accompanying losses in sodium (Na^+) and potassium (K^+) may predispose an individual to heat cramps, exhaustion, or even stroke (2,4,5,6).

Consumption of a carbohydrate-electrolyte (CE) solution to replace fluid, energy, and electrolyte losses might prevent fatigue and heat injury. Alternatively, consuming carbohydrate (CHO) beverages that are too concentrated may reduce gastric emptying and possibly delay rehydration (7,8,9,10). The clearance of CHO solutions from the stomach is delayed as the osmolar concentration of the gastric content increases (6,7). It has been reported that gastric emptying rates of 1.1% and 2.5% carbohydrate (CHO) solutions are not significantly different from water (10), but CHO concentrations greater than 5% have significantly delayed gastric emptying (7,8,9,10). While delayed gastric emptying has not been shown to cause performance degradation, attenuated fluid absorption could contribute to dehydration.

The total carbohydrate delivered from a 5% CE solution is ordinarily inadequate to meet the energy requirements of heavy exercise (7). However, continued ingestion of a CE solution (vs water) during work can stabilize blood glucose levels by supplementing endogenous carbohydrate sources and may extend performance (11,12). Of equal importance is the increased water absorption in the presence of glucose and Na^+ in the small intestine (13). In addition, since flavored water is usually more palatable, it may be consumed in greater quantities and result in less body weight loss (14).

Researchers do not agree on the requirement for electrolyte replacement during work in the heat, particularly if adequate diets are consumed. Thus, dietary recommendations for sodium intake during work in the heat are variable (3,6,15). Current studies recommend that salt be added to the food (maximum intake of 10-15 g salt/day) for workers in the heat

(4,6,16,17,18). However, most of the earlier salt studies were of short duration (<24 hrs) (3,6), did not assess the 10 day period of acclimatization (4,15), or were acute observations on populations who had lived for long periods in the heat (16).

This study was designed to: determine the acceptability of two 2.5% CE solutions; examine the effects of CE solutions on fluid intake in a hot weather field training environment; and evaluate the effects of long term (8 days) consumption of CE solutions on circulating and urinary electrolytes in soldiers consuming an adequate diet.

METHOD

The introductory article includes information on the composition of CE1 and CE2 (19) and the overall physical characteristics of the subjects. Briefly, two lemon-lime 2.5% carbohydrate-electrolyte solutions (CE1 and CE2), plain water (W), and a lemon-lime flavored water placebo (FW) were evaluated for acceptability. Each subject was given one of the four test beverages (CE1, CE2, W, or FW) to consume <u>ad lib</u>, and in addition, was allowed to consume water and other fluids (e.g. milk, soda, etc.) when available.

Soldiers were given fluid intake cards to record the number of canteens of test beverage consumed. The subjects recorded all other fluids that they consumed between meals (e.g., milk, soda, tea, etc.) on these cards. The cards were issued and collected in the AM and PM. Fluid intake during the two hot meals (breakfast and dinner) was recorded by data collectors.

Food intake data were collected at the A-ration breakfast and dinner meals using a modified visual estimation method developed at USARIEM (21). Subjects also recorded lunch (MRE) and snack food intake on the fluid intake card.

A 9-point hedonic scale (1=dislike extremely, 5=neither like nor dislike, and 9=like extremely) (20) was printed on the fluid intake card and was used to rate the daily acceptability of the test beverages. Daily ratings were made during the warmest portion of the day. Acceptability data from an end-of-study questionnaire also were collected to obtain the subjects' general impressions of the test beverages.

Urine was collected twice a day (AM and PM) and analyzed for sodium and potassium concentration. Blood was collected twice during the test period: within 2 hours of arrival at Fort Hood (PM) and during the evening of Day 8. The serum samples were frozen and analyzed for electrolytes using the Kodak Ektachem 700 blood analyzer.

The Statistical Package for the Social Sciences (SPSSx) was used to analyze the data. In the event of a significant difference ($p<0.05$) between groups, post-hoc between group comparisons were made by the Newman-Keuls and Tukey HSD methods. Means $\pm$ SE are reported.

RESULTS

Table 1 shows the mean hedonic ratings for each beverage from the daily and end-of-study evaluations. The values of the daily and end-of-study hedonic ratings were different in terms of absolute amounts but the relative order of the ratings paralleled and supported one another.

Both evaluations indicated that CE2 was liked best and CE1 the least with the difference between the two CE solutions significant. The consumption of CE2 was not significantly different (NS) from CE1 but the

Table 1
Hedonic Ratings of Beverages

Test Beverage	Hedonic Rating: Daily	Hedonic Rating: End-of-Study Questionnaire	Test Beverage Intake (L/d)
CE1	5.1[a]	5.1[a]	2.1±0.2[a]
W	6.5[c]	6.1[a,b]	2.9±0.2[b]
FW	6.6[b,c]	6.6[a,b]	3.0±0.2[b]
CE2	6.7[b]	6.9[b]	2.6±0.2[a,b]

Based on 9-point rating scale where 1=dislike extremely, 5=neither like nor dislike, and 9=like extremely.

Means with unlike superscripts differ, $p<0.05$.

subjects tended to drink more of the beverage with the higher hedonic rating (Table 1). The consumption of W and FW was significantly higher than for CE1 and there were no significant differences between W and the FW placebo in terms of hedonic rating and consumption.

The subjects were allowed to drink the test beverages and plain water *ad libitum*. Data were available to compare the amount of test beverage to the amount of plain water that each subject consumed during the study. The ratio of test beverage to plain water consumption were 4.40 for CE1, 11.42 for FW, and 2.65 for CE2.

Figure 1 shows the dietary sodium intake, urinary excretion, and serum levels during 8 days of work in the heat. The mean sodium intake for all soldiers participating in the study was 4227$\pm$91 mg/day or 10.6 g of salt (NaCl). The mean sodium intake of the W group was significantly lower than that of all other groups including the group drinking FW which was not supplemented with sodium. The pattern of urinary sodium excretion followed sodium intake closely. The serum sodium values decreased significantly pre- to post-FTX for the CE1 and FW groups.

The dietary intake (mean 3.4$\pm$0.07 g), urinary excretion, and blood levels of potassium are shown in Figure 2. There were no significant differences between the groups for potassium intake except for the significantly higher intake in the CE1 group. Inspection of the data showed that the CE1 group drank the potassium-supplemented beverage during the morning period and excreted more potassium in their urine in the afternoon. Serum potassium decreased in all groups except for an increase in CE1. The decrease in serum potassium for all other groups was not physiologically or statistically significant.

DISCUSSION

Daily hedonic ratings showed that CE1 had a significantly lower rating than W, FW, and CE2. The formulation of the CE solutions appears to affect acceptability. The hedonic rating for CE2 was higher than for W and FW but the differences were within two-tenths of a rating point and therefore the acceptability of these three beverages appear to be similar. Acceptability ratings collected on the end-of-study questionnaire showed the same pattern among the four groups with a significant difference only between the least liked CE1 and the most liked CE2. Additional data suggested that the low CE1 ratings may have been due to the perceived saltiness of that beverage. CE2 contained the same amount of sodium as CE1 and yet CE2 received the highest hedonic rating suggesting that the low rating for CE1 was due to the K^+ and Mg^{++} in CE1. Results discussed in a previous report (23) indicated that while subjects who drank CE1 also tended to rate plain water somewhat lower than did subjects in the other groups, this difference was not statistically significant.

The acceptability of the test beverages affected consumption. The subjects in the CE1 consumed less test beverage while those in the FW, W, and CE2 groups consumed more test beverage which reflected the hedonic ratings. The hedonic rating and consumption of W and FW was very similar possibly indicating that coloring and flavoring did not affect consumption of the beverages. When given a choice, soldiers preferred and drank more of the plain or flavored water (no electrolytes), suggesting a greater acceptability of this type of beverage under moderate activity and variable heat conditions.

However, on an individual basis the subjects preferred the coloring and flavoring. Comparison of the consumption of the colored and flavored test beverage to plain water for each subject showed that the soldiers drank more of the colored flavored beverages and continued to prefer the beverage without electrolytes (11.42) to the CE1 and CE2 beverages, 4.40 and 2.65, respectively. The mismatch for the ratios and hedonic ratings may have been due to the fact that the subjects were not allowed to taste and rate the other test beverages, that drinking CE2 may have encouraged water intake, or that hedonic ratings may not reflect consumption.

The soldiers in the field consumed a mean of 10.6 g salt/day in the present study. An active person losing 8-12 liters of sweat/day (17,18) could lose 10-15 g/day of salt. The mean salt intake for the present study was adequate to replace normal losses in sweat. Therefore, supplementation with salt tablets or electrolyte solutions is not necessary. Replacing water while depleting salt could cause marked diuresis with gradual dehydration secondary to electrolyte deficiency (4) and therefore, salting food during heavy sweating usually is recommended (4,6,16,17,18). Several researchers have found that humans engaged in mild to moderate physical work can survive on 1.9 g of salt/day (16,24). The body conserves Na^+ by extremely efficient reabsorption in the kidney resulting in reduced urinary sodium excretion. The results of the present study appear to support the view that the salt from food is sufficient for the body's needs since subjects that were not receiving a sodium-supplemented beverage were still excreting urinary sodium at normal levels indicating adequate dietary intake in all groups. Although the CE1 intake of sodium was one of the highest, urinary excretion in this group was also the highest, which may have contributed to the significant drop in serum sodium for the CE1 group. Although this reduction in serum sodium was statistically significant, the difference was clinically within normal limits and therefore, not physiologically significant for the CE1 group.

The CE1 beverage was supplemented with potassium and dietary intake was also consistently higher for the subjects in this group leading to the only increase in serum potassium. With sufficient food intake, the potassium-supplemented beverage probably was not needed. For example, the FW group consumed amounts of potassium similar to that of the CE1 group while drinking a beverage that was not electrolyte supplemented.

The reasons for the decrement in serum sodium and rise in serum potassium despite high urinary excretion in the CE1 group, are unknown. However, we hypothesize that this combination may result from the ratio of sodium to potassium in CE1 (2.4:1) compared to the CE2 solution (1250:1). It may not be necessary to replace all of the sodium and potassium lost in sweat with CE beverages if food consumption is adequate. In light of these results, the impact of the sodium to potassium ratio in CE solutions on serum electrolytes should be investigated.

According to the clinical chemistries, the ingestion of CE solutions was not accompanied by significant deviations from normal values in serum electrolytes. Thus, this study established the safety of ingesting these beverages under moderate work in the heat. The effectiveness of any of these CE solutions under conditions of severe heat stress cannot be determined from this study and awaits future field studies under intense work and heat conditions.

Under conditions of moderate activity, variable heat stress, and when other colored, flavored beverages are available, there is no evidence that providing a CE solution will enhance fluid consumption and reduce hypohydration when compared to plain water of equivalent temperature. When food intake is adequate, consumption of water or non-nutritive flavored beverages is adequate to maintain electrolyte homeostasis.

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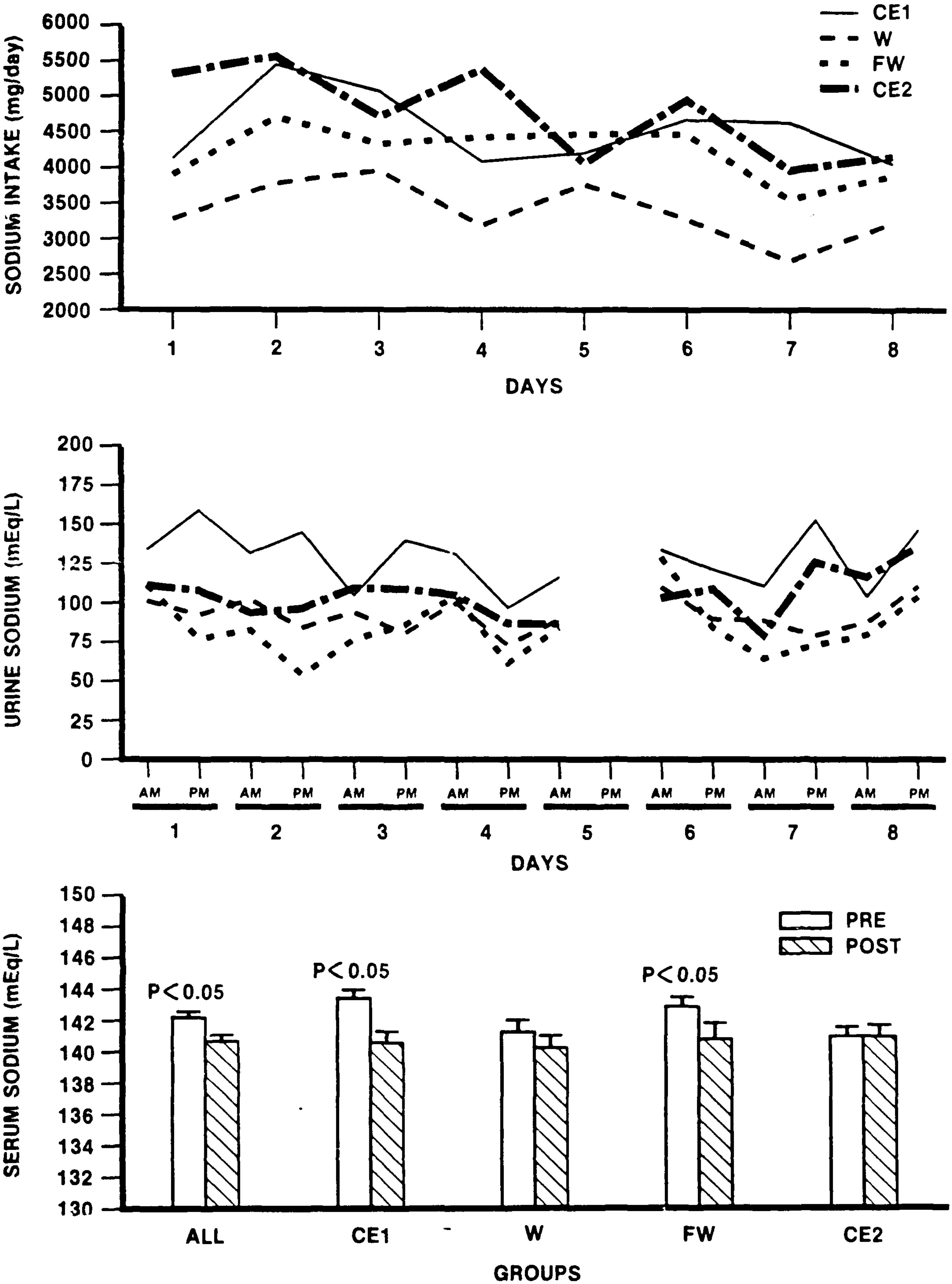
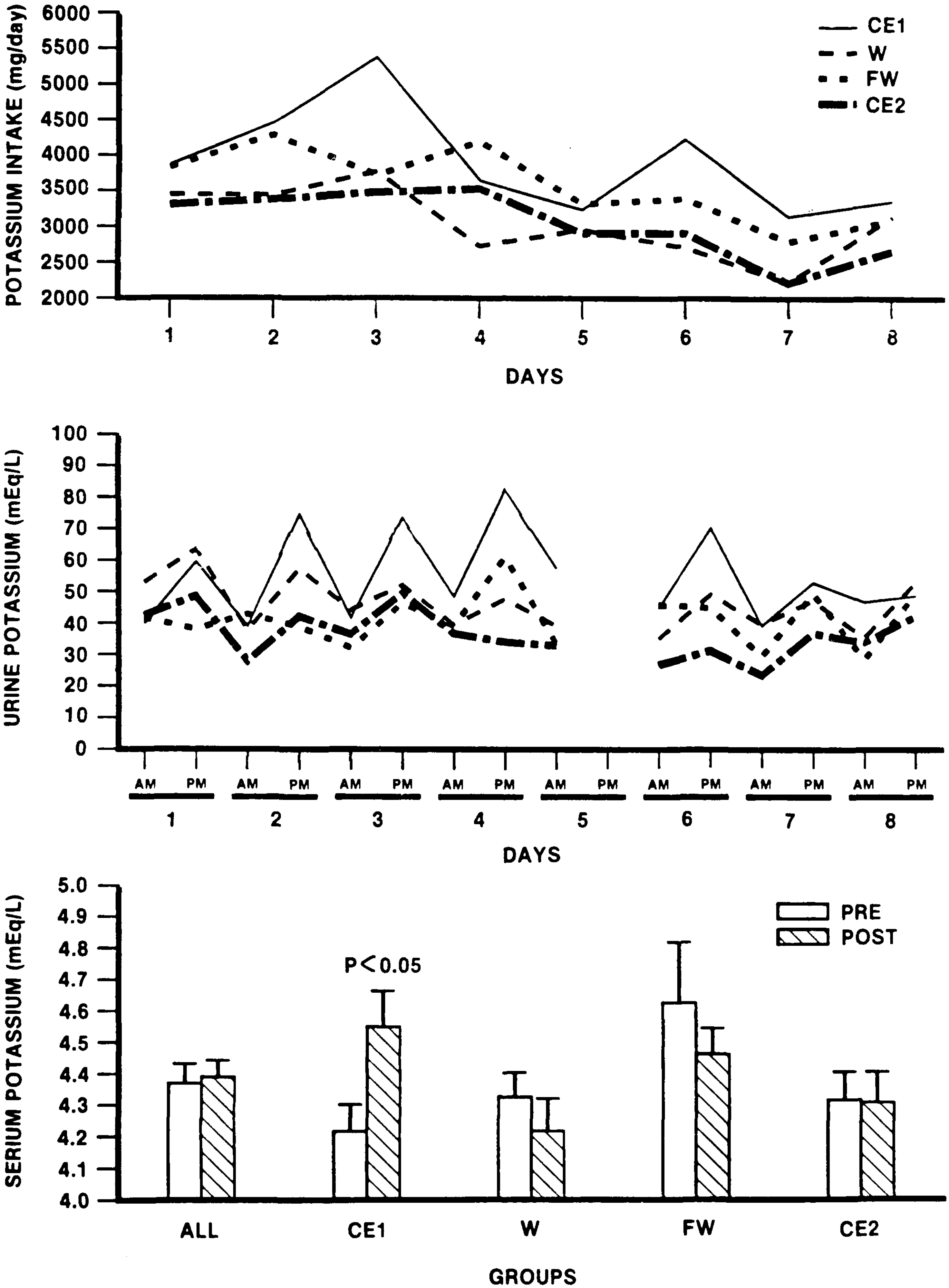
FIGURE LEGENDS

Figure 1. Sodium changes in dietary intake, urinary excretion, and serum values for each of four test beverage groups before, during, and/or after 8 days of work in the heat.

Figure 2. Potassium changes in dietary intake, urinary excretion, and serum values for each of four test beverage groups before, during, and/or after 8 days of work in the heat.



CE1
W
FW
CE2
SODIUM INTAKE (mg/day)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1
2
3
4
5
6
7
8
DAYS
URINE SODIUM (mEq/L)
200
175
150
125
100
75
50
25
0
AM
PM
DAYS
SERUM SODIUM (mEq/L)
150
148
146
144
142
140
138
136
134
132
130
PRE
POST
P<0.05
P<0.05
P<0.05
ALL
CE1
W
FW
CE2
GROUPS


POTASSIUM INTAKE (mg/day)
6000
5500
5000
4500
4000
3500
3000
2500
2000
CE1
W
FW
CE2
1
2
3
4
5
6
7
8
DAYS
URINE POTASSIUM (mEq/L)
100
90
80
70
60
50
40
30
20
10
0
AM
PM
1
2
3
4
5
6
7
8
DAYS
SERIUM POTASSIUM (mEq/L)
5.0
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
PRE
POST
P<0.05
ALL
CE1
W
FW
CE2
GROUPS